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A preclinical screen to evaluate pharmacotherapies for the treatment of agitation in dementia

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ABSTRACT

Agitation associated with dementia is frequently reported clinically but has received little attention in preclinical models of dementia. The current study used a 7PA2 CM intracerebroventricular (ICV) injection model of Alzheimer's disease (AD) to assess acute memory impairment, and a bilateral intrahippocampal (IH) injection model of AD (aggregated A β ₁₋₄₂ injections) and a bilateral IH injection model of dementia with Lewy bodies (DLB; aggregated NAC₆₁₋₉₅ injections) to assess chronic memory impairment in the rat. An alternating-lever cyclic-ratio schedule of operant responding was employed for data collection, where incorrect lever perseverations measured executive function (memory) and running response rates (RRR) measured behavioral output (agitation). The results indicate that bilateral IH injections of A β ₁₋₄₂ and bilateral IH injections of NAC₆₁₋₉₅ decreased memory function and increased RRRs, whereas ICV injections of 7PA2 CM decreased memory function but did not increase RRRs. These findings show that using the aggregated peptide IH injection models of dementia to induce chronic neurotoxicity, memory decline was accompanied by elevated behavioral output. This demonstrates that IH peptide injection models of dementia provide a preclinical screen for pharmacological interventions used in the treatment of increased behavioral output (agitation), that also establish detrimental side effects on memory.

Key Words: Alzheimer's disease; dementia with Lewy bodies; agitation; memory; animal model; pharmacotherapy.

INTRODUCTION

A significant number of patients suffering from dementia exhibit behaviors indicative of agitation (Savva et al., 2009; Ryu et al., 2005) such as restlessness and disturbed sleep (Cipriani et al., 2014), and it has been estimated that approximately 90% of dementia sufferers develop behavioral problems that supersede the seminal symptom of memory dysfunction (Tariot and Blazina, 1993). Agitation is found in Alzheimer's disease (AD), dementia with Lewy bodies (DLB), frontotemporal dementia, and other syndromes resulting in dementia (Burns and Josephs, 2013; Manoochehri and Huey, 2012; Ballard and Corbett, 2010). Agitation has been defined as inappropriate verbal, vocal or motor activity that is unexplained by apparent needs or confusion (Cohen-Mansfield and Billig, 1986). While agitation might include aggressive behaviors, it can occur without aggression (Cummings et al., 2015), and when it is severe it requires pharmacological treatment (Herrmann and Lanctot, 2007). The treatment of agitation has been identified as an unmet need in relation to adequate care provided for those suffering from cognitive impairments (Gitlin et al., 2012; Herrmann and Lanctot, 2007). When the agitation is severe the symptoms include disinhibition, irritability, aggression and aberrant motor activity, which affect the patient's quality of life and cause increased stress for the family and caregivers (Antonsdottir et al., 2015; Cummings et al., 2015; Panza et al., 2015; Kales et al., 2014).

This aspect of dementia has been largely overlooked in the employment of laboratory-based animal models of dementia, where the focus has been directed toward establishing neuropathological and behavioral features reflecting a decline in memory abilities. Agitation related to dementia is frequently observed clinically (Cohen-Mansfield, 2013; Ballard et al., 2001; Lyketsos et al., 2000), and various pharmacological interventions have been employed to treat this. These treatments include the use of anxiolytic, antidepressant, antipsychotic and anticonvulsant drugs (Antonsdottir et al., 2015; Cummings et al., 2015; Panza et al., 2015;

Soto et al., 2015; Kales et al., 2014; Salzman et al., 2008). The most contentious approach relates to the use of antipsychotic drugs (Jeste et al., 2008), which have been reported to be of only modest value (Ballard et al., 2009; Schneider et al., 2006), and to produce adverse effects (Gitlin et al., 2012). Overall, the currently available pharmacological treatments for agitation in dementia are of little value, and the adverse effects of antipsychotic drugs are of considerable concern (Sacchetti et al., 2012; Ma et al., 2014; Ballard, 2006; Schneider et al., 2006). Basically, there are no officially approved pharmacotherapies for agitation in dementia, and few if any safe and effective pharmacotherapies (Antonsdottir et al., 2015; Cummings et al., 2015; Panza et al., 2015; Soto et al., 2015; Kales et al., 2014; Salzman et al., 2008). Also, non-pharmaceutical approaches have been shown to be of very limited value (Ballard et al., 2016; Steinberg, 2016; Kales et al., 2014). Of the pharmacological treatments used for the management of agitation in dementia, benzodiazepines (anxiolytics) have weak effects (Defrancesco et al., 2015; Ngo and Holroyd-Leduc, 2015; Kales et al., 2014; Wilson et al., 2012; Salzman et al., 2008) and have been found to accelerate cognitive deterioration (Defrancesco et al., 2015), the antidepressants citalopram (Pollock et al., 2002) and sertraline (Lyketsos et al., 2003) have been suggested to have some effects (Sink et al., 2005), however the trial using citalopram had a high dropout rate due to lack of efficacy and sertraline had no benefit with respect to neuropsychiatric symptoms. Antipsychotics are of modest value (Gitlin et al., 2012; Ballard et al., 2009) but induce adverse cerebrovascular events, especially during the first weeks of treatment (Wu et al., 2013; Sacchetti et al., 2012) and increase mortality (Ma et al., 2014; Sacchetti et al., 2012; Ballard, 2006; Schneider et al., 2006), and anticonvulsants raise concerns with respect to tolerability (Gallagher and Herrmann, 2014). Consequently, a preclinical model of dementia that measures adverse effects on memory (the seminal symptom of dementia), and also models the agitation commonly observed clinically, would be useful for screening pharmacotherapies for the treatment of agitation in dementia.

The widely known form of dementia is AD, which is associated with the accumulation of amyloid- β ($A\beta$) plaques in the brain (e.g., Glenner and Wong, 1984). It accounts for up to 80% of all cases of dementia (Herbert et al., 2013) and is comprehensively documented. DLB is the second most common form of dementia, it presents in approximately 40% of Parkinson's disease cases (Poewe, 2005), and the severity of DLB correlates significantly with the density of Lewy body (LB) deposition in the brain (Hurtig et al., 2000). While $A\beta_{1-42}$ (the most toxic form of $A\beta$) and $A\beta_{1-40}$ are major components of the aggregated plaques found in AD, aggregated α -synuclein is the major component of LBs (Spillantini et al., 1998), and the non-amyloid component (NAC) region of α -synuclein, residues 61-95 (NAC_{61-95}), is essential for the aggregation and toxicity of α -synuclein (El-Agnaf et al., 1998). NAC_{61-95} was first isolated from the amyloid plaques associated with AD (Ueda et al., 1993), and this region of α -synuclein has been linked with an increased propensity of α -synuclein to form fibrils (Jethva et al., 2011). The fibrillogenic capacity of NAC_{61-95} is well documented, and the extracellular aggregation of NAC and intracellular accumulation of α -synuclein are considered to be contributory factors in the pathogenesis of DLB and AD.

Consequently, to determine whether an animal model of dementia can reflect the increased behavioral output (agitation) commonly reported in clinical observations of patients suffering from dementia, the current study employed a bilateral intrahippocampal (IH) injection model of the effect of aggregated $A\beta_{1-42}$ in AD, and a bilateral IH injection model of the effect of aggregated NAC_{61-95} in DLB to produce chronic neurotoxic peptide deposits in the brain. While recent theories relating to the onset of dementia, and in particular AD, suggest that the precipitating event is the disruption of synaptic transmission due to the formation of the oligomeric configuration of the neurotoxic peptide (e.g., Ondrejcek et al., 2010; Pharm et al., 2010; Klyubin et al., 2008; Shankar et al., 2008; Haas and Selkoe, 2007; Walsh and Selkoe, 2007), very few patients presenting clinically with symptoms of memory

decline are likely to be at such an early stage of disease progression. However, the intracerebroventricular (ICV) 7PA2 CM injection model of AD (e.g., Cleary et al., 2005) was employed to determine the effects of acute synaptotoxicity on increased behavioral output, even though clinical management of typical dementia cases generally involves the use of drugs for the treatment of agitation following diagnosis at the stage of pathogenesis when aggregated neurotoxic peptides are chronically established in the brain.

The operant technique employed was the alternating-lever cyclic-ratio (ALCR) schedule (Weldon et al., 1996). This experimental evaluation of behavior has been used to assess the effects of bilateral IH injections of aggregated A β ₁₋₄₂ (Richardson et al., 2002; O'Hare et al., 1999), bilateral IH injection of aggregated NAC₆₁₋₉₅ (O'Hare et al., 2010a,b; Kim et al., 2009), and ICV injections of 7PA2 CM in the rat (e.g., Poling et al., 2008; Cleary et al., 2005). The aggregated peptide injections were delivered into the hippocampus as this is an area of the brain directly implicated in learning and memory (Jerrard, 1993), and the ALCR schedule was used as this is recognized as a sensitive, accurate and parsimonious determinant of memory function in the rat (Poling et al., 2008; Cleary et al., 2005). Also, the ALCR provides data indicating experimental effects on running response rates (RRRs). RRRs illustrate increases or decreases in behavioral output, and increased RRRs may be analogous to the increased behavioral output seen as agitation in human dementia.

The RRR is the rate of lever press responding at any given operant ratio response value, minus the post-reinforcement pause duration (Ferster and Skinner, 1957). The post-reinforcement pause duration is the time spent after receiving a reinforcer (generally a food pellet for experimental animals) prior to beginning the next lever press engagement for production of the next reinforcer. Consequently, RRRs provide a measure of actual lever pressing activity per unit of lever pressing time. This observation is generally incorporated in operant experiments to ensure that malaise or peripheral motor impedance resulting from an

experimental manipulation is not misinterpreted as an adverse central nervous system effect on memory-related behavioral measurements. That is, an observed decline in cognitive (memory) ability that correlates with a reduction in RRRs might simply be a reflection of the physical inability of an animal, due to malaise or illness, to complete a required task (seen as a decrease in activity, and misinterpreted as an effect on memory). In the current study, data on RRRs were collected to determine whether the induction of neurotoxicity might affect RRRs in a manner that indicated the development of agitation. These data were used to determine whether an increase in RRRs, possibly inferring the agitation commonly seen in the syndrome reported for human patients suffering from dementia, was an inherent feature of experimentally-induced memory dysfunction due to acute synaptotoxicity (ICV 7PA2 CM injections), or chronic neurotoxicity due the presence of neurotoxic peptide aggregates in the hippocampal region of the brain.

METHODS

Subjects

Forty eight male Sprague-Dawley rats (Harlan, UK), weighing 229-250 g at the beginning of the experiment were maintained at 90% of their free-feeding body weights, and housed individually with water available *ad libitum* in the home cage. The temperature in the *vivarium* was maintained at 23°C under a 12 h light/12 h dark cycle (lights on at 0800 h). The relative humidity of the vivarium was maintained at 50-65%, and light intensity was controlled at a maximum of 9 lux in the home cage. This work was approved by the relevant institutional ethics committees and conducted under Home Office License (UK).

Apparatus

Ten two-lever rat test chambers (Med Associates Inc, St Albans, NJ, USA) enclosed in sound attenuating compartments were employed. Food reinforcers were 45 mg sucrose food pellets (BioServ, Frenchtown, NJ, USA) that were delivered into a tray situated midway between the two operant levers. A Siemens computer programmed in MED-PC (Med Associates Inc, St Albans, NJ, USA) controlled the experiment and collected data. The operant test chambers had internal dimensions of 30.5 cm long x 24.1 cm wide x 21 cm high, the pellet receptacle was 2.9 cm wide x 2.5 cm high x 1.9 cm deep, and was situated in the center of the 24.1 cm chamber wall. The retractable operant response levers were 4.8 cm wide x 1.9 cm deep and were positioned 2.1 cm above the floor of the chamber on each side of the pellet receptacle. The house light was situated in the center of the chamber ceiling, and when illuminated had an output of 3 W.

Behavioral training

The training procedure employed has previously been reported extensively (e.g., Cleary et al., 2005; Richardson et al., 2002; Weldon et al., 1996). Briefly, behavioral sessions were conducted 7 d/wk, during which the rats were trained to press both levers for food reinforcement, each operant training session lasted for a maximum of 50 min. Over approximately 20-30 sessions following initial lever press training, the ALCR schedule was introduced. Using this schedule, rats alternate to the other lever after pressing the currently correct lever a sufficient number of times to obtain a food reinforcer. The number of lever presses required for each reinforcer changes, increasing from 2 responses per food pellet up to 56 responses per food pellet, and then decreasing back to 2 responses per food pellet, repeated over 6 cycles. One complete cycle requires alternating-lever responses of 2, 6, 12, 20, 30, 42, 56, 56, 42, 30, 20, 12, 6 and 2. This generates data on incorrect lever perseverations, which indicate disruption of well-learned behaviors, or reference memory,

including general aspects of executive function, reasoning, and goal-oriented manipulation of previously acquired information (Poling et al., 2008; Cleary et al., 2005). The ALCR schedule also measures RRRs; these are response rates at each schedule value, minus the post-reinforcement pause duration. Consequently, RRRs provide a measure of actual lever pressing activity per unit of lever pressing time, thereby indicating the general level of activity.

7PA2 Conditioned Medium

7PA2 cells are stably transfected Chinese hamster ovary cells which incorporate the cDNA for amyloid precursor protein (APP751), this is specific for the familial AD mutation Val171Phe (Shankar et al., 2011; Podlisny et al., 1998). These cells secrete $A\beta_{1-40}$ and $A\beta_{1-42}$ (Shankar et al., 2011), and were grown to just below confluence in DMEM containing 10% FBS and 200 $\mu\text{g/ml}$ G418. They were briefly washed in DPS and incubated at 37°C with 5% CO_2 for 18 h with a sufficient volume of DMEM to cover the cells. After incubation the medium was centrifuged at 3000 g for 15 min and snap frozen and stored at -20°C until thawing for ICV injections. Using ELISA, the concentration of total $A\beta$ in the 7PA2 CM was in the range of 2-5 nM.

Aggregation of $A\beta_{1-42}$ and NAC_{61-95}

Aggregated $A\beta_{1-42}$ and aggregated NAC_{61-95} were prepared from solutions of 10^{-4} M soluble $A\beta_{1-42}$ or soluble NAC_{61-95} peptides (Sigma, UK) in 0.01 M filtered phosphate buffered saline (PBS; pH 7.4) (Weldon et al., 1998). The $A\beta_{1-42}$ and NAC_{61-95} solutions were agitated (Teflon-coated stirbar at 200 rpm) at room temperature for 36 h. Following agitation, both solutions ($A\beta_{1-42}$ and NAC_{61-95}) were turbid. The $A\beta_{1-42}$ and NAC_{61-95} peptides were then sedimented by centrifugation (10 min X 15,000 g) to 80% sedimentation of each peptide.

These sediments of aggregated A β ₁₋₄₂ and aggregated NAC₆₁₋₉₅ were then dissolved with PBS, aliquoted and stored at -20°C prior to thawing for bilateral IH injections.

Surgical procedure

When all rats were capable of completing the ALCR schedule in 50 min without demonstrating changes in operant response trends, they were anaesthetized with fentanyl citrate (0.4 ml/kg) and placed in a stereotaxic frame (Kopf, USA). For ICV injections (7PA2 CM administration), sixteen rats were fitted with a permanently indwelling cannula (23 gauge) aimed at the lateral cerebral ventricle. Half of the rats in each randomly assigned group (experimental and control) received left lateral ventricle cannula implants and the other half received right lateral ventricle cannula implants. With the incisor bar set 3.5 mm below the interaural line, the stereotaxic coordinates for cannula implantation were 1.0 mm posterior and \pm 1.5 mm lateral to bregma, and 3.0 mm below the pial surface (Paxinos and Watson, 1998). Cannula placement and patency was verified by vigorous drinking (>5 ml/20 min) following ICV injection of 0.5 μ g/ml of angiotensin II (Johnson and Epstein, 1974). Following a 7 d recovery period from surgery, the experimental group was injected ICV with 10 μ l of 7PA2 CM and the control group was injected ICV with 10 μ l of CHO CM (wild-type control), and initial behavioral testing was conducted 2 h following ICV injections. This temporal sequence for behavioral testing following 7PA2 CM ICV injections has been previously explained, and the effect on memory dissipates within 24 h post-injection (Cleary et al., 2005).

For IH injections (aggregated A β ₁₋₄₂ and aggregated NAC₆₁₋₉₅) the remaining thirty two rats were fitted with permanently indwelling bilateral cannulae aimed at the CA3 region of the dorsal hippocampus of the brain, with the incisor bar set 3.5 mm below the interaural line, the stereotaxic coordinates were 3.3 mm posterior and \pm 2.6 mm lateral to bregma, and

3.7 mm below the pial surface (Paxinos and Watson, 1998). Following a 7 d recovery period from surgery the rats were randomly assigned to groups. Sixteen rats were assigned to the aggregated A β ₁₋₄₂ experimental group, of which eight received bilateral IH injection of aggregated A β ₁₋₄₂ and eight received bilateral IH injection of sterile water, and sixteen rats were assigned to the aggregated NAC₆₁₋₉₅ group, of which eight received bilateral IH injection of aggregated NAC₆₁₋₉₅ and eight received bilateral IH injection of sterile water. These experimental subjects were injected bilaterally IH with 5 μ l (per side) of aggregated A β ₁₋₄₂ (n=8) and the corresponding control group was injected bilaterally IH with 5 μ l (per side) of sterile water (n=8), the remaining IH group was injected with bilaterally IH with 5 μ l (per side) of aggregated NAC₆₁₋₉₅ (n=8) and the corresponding control group was injected bilaterally IH with 5 μ l (per side) of sterile water (n=8). Using a 26 gauge needle connected to a Hamilton microsyringe, injectates were deposited slowly over a 15 min period, and the injector remained in place for a further 2 min. Sterile water was used as the control injectate because this was the case in other behavioural studies of this nature, and adhering to this procedure ensured that the data were comparable to those of previously published studies. Ten days after the bilateral IH injections, the collection of behavioral data resumed. Data were collected daily from all six cycles of the ALCR schedule for each subject in each group. Following the collection of behavioral data from the IH injected groups (aggregated A β ₁₋₄₂ and aggregated NAC₆₁₋₉₅ and their IH injected sterile water control counterparts), these rats were then bilaterally injected IH with 1 μ l of Evans blue (per side). All of the IH injected rats were then deeply anaesthetized and perfused through the ascending aorta with 4% paraformaldehyde. Using a cryostat, the brains were then sectioned through the plane of the IH microinjection sites and viewed using a light microscope for confirmation of the position of each IH injection.

Statistical analyses

The ICV 7PA2 CM vs CHO CM data on incorrect lever perseverations were analysed by t-test per day (Fig. 1), and the ICV 7PA2 CM RRR data were analysed by repeated measures ANOVA (Fig. 2). The aggregated A β ₁₋₄₂ vs sterile water data and the aggregated NAC₆₁₋₉₅ vs sterile water data on incorrect lever perseverations were analysed by t-test (Fig. 3). The RRR data (A β ₁₋₄₂ and NAC₆₁₋₉₅) were analysed by daily t-tests in the first instance for deviation from the control condition, and then by repeated measures ANOVA within and between groups (Fig. 4, 5). ICV 7PA2 injection effects on memory have previously been shown to last for less than 24 hours, and IH aggregated peptide injection effects on memory have previously been shown to take approximately 30 days to develop.

RESULTS

ICV injections of 7PA2 CM produced an acute increase in incorrect lever perseverations (Fig. 1), indicating a decline in cognitive ability [$t=5.33$, $p<0.001$]. This acute effect of 7PA2 CM-induced synaptotoxicity on behaviour, lasting for less than 1 day, has been previously reported (e.g., Cleary et al., 2005). And, ICV 7PA2 CM injection had no acute or chronic (up to 50 days post-injection) effect on RRRs within the groups [7PA2 CM; $F_{50,350}=1.21$, $p=0.16$ CHO CM; $F_{50,350}=1.11$, $p=0.18$] or between the groups [$F_{1,14}=0.01$, $p=0.90$] (Fig. 2).

Bilateral IH injection of aggregated A β ₁₋₄₂, and bilateral IH injection of aggregated NAC₆₁₋₉₅ produced a chronic increase in incorrect lever perseverations, indicating a decline in cognitive ability [A β ₁₋₄₂ vs sterile water; $t=-24.62$, $p<0.001$; NAC₆₁₋₉₅ vs sterile water; $t=-18.89$, $p<0.001$] (Fig 3) from approximately day 30 onward. This finding is consistent with the effects of IH aggregated peptide injections on operant behaviour in the rat since its first investigation (Cleary et al., 1995), and has previously been reported for IH injections of aggregated A β ₁₋₄₂ (e.g., O'Hare et al., 1999), and for aggregated NAC₆₁₋₉₅ (e.g., Kim et al.,

2009) [$A\beta_{1-42}$ vs sterile water day 1-29; $t=-1.30$, $p>0.05$; NAC_{61-95} vs sterile water day 1-29; $t=-1.22$, $p>0.05$]. There were no significant differences in RRRs during approximately the first 35 days following bilateral IH injection of aggregated $A\beta_{1-42}$ (Fig. 4), however RRRs increased significantly in the aggregated $A\beta_{1-42}$ group from this point until the end of the study (p 's <0.001). Repeated measures analyses indicated a significant effect within the groups by days [$A\beta_{1-42}$; $F_{80,560}=8.93$, $p<0.001$: sterile water; $F_{80,560}=4.26$, $p<0.001$] and between the groups [$F_{1,14}=9.19$, $p<0.001$]. There were no significant differences in RRRs during approximately the first 35 days following bilateral IH aggregated NAC_{61-95} injection (Fig. 5), however RRRs increased significantly in the NAC_{61-95} group from this point until the end of the study (p 's <0.01). Repeated measures analyses indicated a significant effect within the groups by days [NAC_{61-95} ; $F_{80,560}=7.76$, $p<0.001$: sterile water; $F_{80,560}=3.82$, $p<0.001$] and between the groups [$F_{1,14}=5.51$, $p<0.05$].

DISCUSSION

The current study employed animal models of the two most prevalent forms of dementia, AD and DLB (Herbert et al., 2013; Poewe, 2005). In order to establish whether acute synaptotoxicity was linked to increased behavioral output, the 7PA2 CM ICV injection model of AD was employed, and in order to determine whether chronic neurotoxicity was linked to increased behavioural output the bilateral IH injection model of AD (aggregated $A\beta_{1-42}$), and the bilateral IH injection model of DLB (aggregated NAC_{61-95}) were employed. The chronic IH aggregated peptide injection models were more likely to approximate the stage of clinical dementia encountered by physicians at the point of diagnosis of dementia, and at the later stages of pathogenesises where agitation might be encountered.

The current study found that ICV injection of 7PA2 CM produced an acute memory deficit, with full recovery at 24 h post injection, as measured by incorrect lever perseverations

(Fig. 1), but had no effect on RRRs, even at an extended latency (Fig. 2). This effect of 7PA2 CM on memory has been reported extensively (e.g., O'Hare et al., 2016) but not the effect on RRRs. Bilateral IH injection of aggregated A β ₁₋₄₂ and bilateral IH injection of aggregated NAC₆₁₋₉₅ produced a significant increase in incorrect lever perseverations (Fig. 3), and these findings are also in agreement with previous investigations [A β ₁₋₄₂ (e.g., O'Hare et al., 1999), and NAC₆₁₋₉₅ (e.g., O'Hare et al., 2010b)]. Incorrect lever perseverations provide a measure of the disruption of reference memory, including general aspects of executive function, reasoning, and goal-oriented manipulation of acquired information (Poling et al., 2008; Cleary et al., 2005).

RRRs are generally measured as a safeguard to ensure that decreases in RRRs are not misconstrued as direct central nervous system effects. Consequently, they are usually measured to provide information on the general state of health of an experimental animal, and a fall in RRRs accompanied by a decrease in cognitive ability would indicate that any conclusion suggesting central effects might be the result of an experimental confound. IH injections of aggregated A β ₁₋₄₂ and aggregated NAC₆₁₋₉₅ resulted in memory deficits (Fig. 3), and RRRs increased following IH injections of aggregated A β ₁₋₄₂ (Fig. 4) and aggregated NAC₆₁₋₉₅ (Fig. 5). These findings indicate that the IH aggregated peptide injection models employed here determined detrimental effects on memory function, and associated effects on increased behavioral output (agitation). These findings are important because while there is one mouse model of AD in which APP23 mice have been found to show memory deficits and increased aggressiveness (Vloeberghs et al., 2006), there is very little in the literature of preclinical models of dementia that addresses the issue of memory decline and a correlation with extraneous problematic behaviors. Yet problem behaviors, such as agitation are highly prevalent in dementia, and specific pharmacological interventions that have not been screened against overall outcomes for the patient are frequently used in their treatment.

A recent review of investigational compounds for the treatment of agitation in dementia (Garay et al., 2016) considered the efficacy of drugs in ongoing or newly completed clinical trials. This review identified 24 clinical trials, drugs in phase III included an antipsychotic, an antidepressant, a novel compound (AVP-786), and a cannabinoid, and in phase II scyllo-inositol (ELND005) was likely to progress to phase III. Therefore, some headway is being made in this area. Consequently, a preclinical *in-vivo* screen using established procedures for modelling dementia would be of considerable value. Clinically, agitation in dementia is frequently observed and can range from constant vocalization, wandering, and severe sleep disturbances, but it has not been given the research emphasis applied to the basic neurophysiological etiology of memory dysfunction in dementia. However, the management of agitation, psychotic and other non-memory related symptoms of dementia is a major clinical concern. There is a growing recognition that neuropsychiatric symptoms, such as agitation, might increase the rate of progression of dementia. And this is particularly relevant to AD, where it has been found that neuropsychiatric symptoms, such as psychosis, agitation and aggression were associated with a more rapid progression to severe dementia and reduced survival times (Peters et al., 2015).

A range of pharmacological agents have been employed in attempts to treat behavioral problems related to dementia; these include anxiolytic drugs, antidepressant drugs, anticonvulsant drugs, α - and β -adrenergic drugs, lithium, hormones, and antipsychotic drugs. However, the emphasis of preclinical laboratory-based modelling of dementia has tended to concentrate on memory dysfunction, because pharmacological interventions for memory dysfunction are seen as a major research target. As a result, extension of the models employed to investigate memory to other symptoms commonly reported in the clinical literature have largely been overlooked. The findings of the current study indicate that the technique of bilateral IH injection of pre-aggregated peptides, aggregated A β_{1-42} as a model

of AD and aggregated NAC₆₁₋₉₅ as a model of DLB, can be extended to provide a useful *in vivo* animal model of the syndrome of agitation that is commonly associated with cognitive decline in dementia. This model could be used to investigate pharmacological interventions for agitation, including aggressive behaviors and sleep disturbances associated with the disease process. Adopting the preclinical approach to modeling agitation described in the current study would present a method for screening drugs that have ameliorative effects on emerging problem behaviors, but that do not have detrimental effects on the memory functions that have already been compromised by the accumulation of neurotoxic aggregates in the brain.

REFERENCES

- Antonsdottir IM, Smith J, Keltz M, Porsteinsson AP (2015), Advancements in the treatment of agitation in Alzheimer's disease. *Expert Opin Pharmacother* **16**: 1649-56.
- Ballard CJW (2006), The effectiveness of atypical antipsychotics for the treatment of aggression and psychosis in Alzheimer's disease. *Cochrane Database Syst Rev* **1**: CD003476.
- Ballard C, Corbett A (2010), Management of neuropsychiatric symptoms in people with dementia. *CNS Drugs* **24**: 729-39.
- Ballard C, Corbett A, Chitramohan R, Aarsland D (2009), Management of agitation and aggression associated with Alzheimer's disease: controversies and possible solutions. *Curr Opin Neuropsychiatry* **22**: 532-40.
- Ballard C, O'Brien J, Gray A, Cormack F, Ayre G, Rowan E, et al. (2001), Attention and fluctuating attention in patients with dementia with Lewy bodies and Alzheimer's disease. *Arch Neurol* **58**: 977-82.
- Ballard C, Orrell M, YongZhong S, Moniz-Cook E, Stafford J, Whittaker R, et al. (2016), Impact of antipsychotic review and neuropharmacological intervention on antipsychotic use, neuropsychiatric symptoms, and mortality in people with dementia living in nursing homes: a factorial cluster-randomized controlled trial by the Well-Being and Health for People With Dementia (WHELD) Program. *Am J Psychiatry* **173**: 152-262.
- Burns MB, Josephs KA (2013), Neuropsychiatry of corticobasal degeneration and progressive supranuclear palsy. *Int Rev Psychiat* **25**: 197-9.
- Cipriani G, Lucetti C, Nuti A, Danti S (2014), Wandering and dementia. *Psychogeriatrics* **14**: 135-42.
- Cleary J, Hittner JM, Semotuk MT, Mantyh PW, O'Hare E (1995), Beta-amyloid (1-40): effects on behavior and memory. *Brain Res* **682**: 69-74.

- Cleary JP, Walsh DM, Hofmeister JJ, Shankar GM, Kuskowski MA, Selkoe DJ, et al. (2005), Natural oligomers of the beta-amyloid protein specifically disrupt cognitive function. *Nat Neurosci* **8**: 79-84.
- Cohen-Mansfield J (2013), Neuropharmacologic treatment of behavioral disorders in dementia. *Curr Treat Options Neurol* **15**: 765-85.
- Cohen-Mansfield J, Billig N (1986), Agitated behaviors in the elderly. I. A conceptual review. *J Am Geriatr Soc* **34**: 711-21.
- Cummings J, Mintzer J, Brodaty H, Sano M, Banerjee S, Devanand DP, et al. (2015), Agitation in cognitive disorders: International Psychogeriatric Association provisional consensus clinical and research definition. *Int Psychogeriatrics* **27**: 7-17.
- Defrancesco M, Marksteiner J, Fleischhacker WW, Blasko I (2015), Use of benzodiazepines in Alzheimer's disease: a systematic review of literature. *Int J Neuropsychopharmacol* **18**: pyv055.
- El-Agnaf OM, Bodles AM, Guthrie DJ, Harriott P, Irvine GB (1998), The N-terminal region of non-A β component of Alzheimer's disease amyloid is responsible for its tendency to assume β -sheet and aggregate to form fibrils. *Eur J Biochem* **258**: 157-63.
- Ferster CB, Skinner BF (1957), Schedules of Reinforcement. New York: Appleton-Century-Croft.
- Gallagher D, Herrmann N (2014), Antiepileptic drugs for the treatment of agitation and aggression in dementia: do they have a place in therapy? *Drugs* **74**: 1747-55.
- Garay RP, Citrome L, Grossberg GT, Cavero I, Llorca PM (2016), Investigational drugs for treating agitation in persons with dementia. *Expert Opin Investig Drugs* **25**: 973-83.
- Gitlin LN, Kales HC, Lyketsos CG (2012), Neuropharmacologic management of behavioral symptoms in dementia. *JAMA* **308**: 2020-29.

Glenner GG, Wong CW (1984), Alzheimer's disease: initial report of the purification and characterization of a novel cerebrovascular amyloid protein. *Biochem Biophys Res Commun* **120**: 885-90.

Haas C, Selkoe DJ (2007), Soluble protein oligomers in neurodegeneration: lessons from the Alzheimer's amyloid beta-peptide. *Nat Rev Mol Cell Biol* **8**: 101-12.

Hebert LE, Weuve J, Scherr PA, Evans DA (2013), Alzheimer disease in the United States (2010-2050) estimated using the 2010 census. *Neurology* **80**: 1778-83.

Herrmann N, Lanctot KL (2007), Pharmacologic management of neuropsychiatric symptoms of Alzheimer's disease. *Canad J Psychiat* **52**: 630-46.

Hurtig HI, Trojanowski JQ, Galvin J, Ewbank D, Schmidt ML, Lee VM, et al. (2000), Alpha-synuclein cortical Lewy bodies correlate with dementia in Parkinson's disease. *Neurology* **54**: 1916-21.

Jerrard LE (1993), On the role of the hippocampus in learning and memory in the rat. *Behav Neural Biol* **60**: 9-26.

Jeste DV, Blazer D, Casey D, Meeks T, Salzman C, Schneider L, et al. (2008), ACNP White Paper: Update on use of antipsychotic drugs in elderly persons with dementia. *Neuropsychopharmacology* **33**: 957-70.

Jethva PN, Kardani JR, Roy I (2011), Modulation of α -synuclein aggregation by dopamine in the presence of MPTP and its metabolite. *FEBS J* **278**: 1688-98.

Johnson AK, Epstein AN (1974), The cerebral ventricles as the avenue for the dipsogenic action of intracranial angiotensin. *Brain Res* **86**: 399-418.

Kales HC, Gitlin LN, Lyketsos CG (2014), Management of neuropsychiatric symptoms of dementia in clinical settings: recommendations from a multidisciplinary expert panel. *J Am Geriatr Soc* **62**: 762-9.

- Kim E-M, Elliott JJ, Hobson P, O'Hare E (2009), Effects of intrahippocampal NAC61-95 injections on memory in the rat and attenuation with vitamin E. *Prog Neuropsychopharmacol Biol Psychiatry* **33**: 945-51.
- Klyubin I, Betts V, Welzel AT, Biennow K, Zatterberg H, Wallin A, et al. (2008), Amyloid beta protein dimer-containing human CSF disrupts synaptic plasticity: prevention by systemic passive immunization. *J Neurosci* **28**: 4231-7.
- Lyketsos CG, DelCampo L, Steinberg M, Miles Q, Steele CD, Munro C, et al. (2003), Treating depression in Alzheimer disease: efficacy and safety of sertraline therapy, and the benefits of depression reduction: the DIADS. *Arch Gen Psychiatry* **60**: 737-46.
- Lyketsos CG, Steinberg M, Tschanz JT, Norton MC, Steffens DC, Breitner JC (2000), Mental and behavioral disturbances in dementia: findings from Cache County Study on Memory and Aging. *Am J Psychiatry* **157**: 708-14.
- Ma H, Huang Y, Cong Z, Wang Y, Jiang W, Gao S, et al. (2014), The efficacy and safety of atypical antipsychotics for the treatment of dementia: a meta-analysis of randomized placebo-controlled trials. *J Alzheimers Dis* **42**: 915-37.
- Manoochehri M, Huey ED (2012), Diagnosis and management of behavioral issues in frontotemporal dementia. *Curr Neurol Neurosci Rep* **12**: 528-36.
- Ngo J, Holroyd-Leduc JM (2015), Systematic review of recent dementia practice guidelines. *Age Ageing* **44**: 25-33.
- O'Hare E, Elliott JJ, Hobson P, O'Mara SM, Spanswick D, Kim E-M (2010a), Bilateral intrahippocampal NAC61-95 effects on behavior and moderation with L-NAME treatment. *Neurosci Res* **66**: 213-18.
- O'Hare E, Elliott JJ, Hobson P, Spanswick D, Kim E-M (2010b), Behavioral deterioration induced by intrahippocampal injection NAC61-95 and attenuation with ibuprofen. *Behav Brain Res* **208**: 274-7.

- O'Hare E, Jeggo R, Kim E-M, Barbour B, Walczak J-S, Palmer P, et al. (2016), Lack of support for bexarotene as a treatment for Alzheimer's disease. *Neuropharmacol* **100**: 124-30.
- O'Hare E, Weldon DT, Mantyh PW, Ghilardi JR, Finke MP, Kuskowski MA, et al. (1999), Delayed behavioral effects following intrahippocampal injection of aggregated Abeta (1-42). *Brain Res* **815**: 1-10.
- Ondrejcek T, Klyubin I, Hu NW, Barry AE, Cullen WK, Rowan MJ (2010), Alzheimer's disease amyloid beta-protein and synaptic function. *Neuromolecular Med* **12**: 13-26.
- Panza F, Solfrizzi V, Seripa D, Imbimbo BP, Santamato A, Lozupone M, Prete et al. (2015), Progress in treating agitation: a major clinical challenge in Alzheimer's disease. *Expert Opin Pharmacother* **16**: 2581-8.
- Paxinos G, Watson C (1998), The Rat Brain in Stereotaxic Coordinates. New York: Academic Press.
- Peters ME, Schwartz S, Han D, Rabins PV, Stinberg M, Tschanz JT, et al. (2015), Neuropsychiatric symptoms as predictors of progression to severe Alzheimer's dementia and death: the Cache County dementia progression study. *Am J Psychiatry* **172**: 460-5.
- Pharm E, Crews L, Ubhi K, Hansen L, Adame A, Cartier A, et al. (2010), Progressive accumulation of amyloid-beta oligomers in Alzheimer's disease and in amyloid precursor protein transgenic mice is accompanied by selective alterations in synaptic scaffold proteins. *FEBS J* **277**: 3051-67.
- Poewe W (2005), Treatment of dementia with Lewy bodies and Parkinson's disease dementia. *Mov Disord* **20**: S77-S82.
- Podlisny MB, Walsh DM, Amorante P, Ostaszewski BL, Stimson ER, Maggio JE, et al. (1998), Oligomerization of endogenous and synthetic amyloid beta-protein at nanomolar levels in cell culture and stabilization of monomer by Congo red. *Biochemistry* **37**: 3602-11.

Poling A, Morgan-Paisley K, Panos JJ, Kim E-M, O'Hare E, Cleary JP, et al. (2008), Oligomers of the amyloid beta protein disrupt working memory: confirmation with two behavioral procedures. *Behav Brain Res* **193**: 230-4.

Pollock BG, Mulsant BH, Rosen J, Sweet RA, Mazumdar S, Bharucha A, et al. (2002), Comparison of citalopram, perphenazine, and placebo for the acute treatment of psychosis and behavioral disturbances in hospitalized, demented patients. *Am J Psychiatry* **159**: 460-5.

Richardson RL, Kim E-M, Shephard RA, Gardiner T, Cleary J, O'Hare E (2002), Behavioral and histopathological analyses of ibuprofen treatment on the effect of aggregated Abeta₍₁₋₄₂₎ injections in the rat. *Brain Res* **954**: 1-10.

Ryu SH, Katona C, Rive B, Livingston G (2005), Persistence of and changes in neuropsychiatric symptoms in Alzheimer's disease over six months: The LASER AD Study. *Am J Geriatr Psychiatry* **13**: 976-83.

Sacchetti E, Turrina C, Valsecchi P (2012), Cerebrovascular accidents in elderly people treated with antipsychotic drugs. *Drug Safety* **33**: 273-88.

Salzman C, Jeste D, Meyer RE, Cohen-Mansfield J, Cummings J, Grossberg GT, et al. (2008), Elderly patients with dementia-related symptoms of severe agitation and aggression: consensus statement on treatment opinions, clinical trials methodology, and policy. *J Clin Psychiatry* **69**: 889-98.

Savva GM, Zaccai J, Matthews FE, Davidson JE, McKeith I, Brayne C (2009), Prevalence, correlates and course of behavioral and psychological symptoms of dementia in the population. *Br J Psychiatry* **194**: 212-9.

Schneider LS, Dagerman K, Insel PS (2006), Efficacy and adverse effects of atypical antipsychotics for dementia: meta-analysis of randomized, placebo-controlled trials. *Am J Geriatr Psychiatry* **14**: 191-210.

- Schneider LS, Tariot PN, Dagerman KS, Davis SM, Hsiao JK, Ismail MS, et al. (2006), Effectiveness of atypical antipsychotic drugs in patients with Alzheimer's disease. *N Engl J Med* **355**: 1525-38.
- Shankar GM, Li S, Mehta TH, Garcia-Munoz A, Shepardson NE, Smith I, et al. (2008), Amyloid- β protein dimers isolated directly from Alzheimer's brains impair synaptic plasticity and memory. *Nat Med* **14**: 837-42.
- Shankar GM, Welzel AT, McDonald JM, Selkoe DJ, Walsh DM (2011), Isolation of low-n amyloid β -protein oligomers from cultured cells, CSF, and brain. *Methods Mol Biol* **670**: 33-44.
- Sink KM, Holden KF, Yaffe K (2005), Pharmacological treatment of neuropsychiatric symptoms of dementia. *JAMA* **293**: 596-608.
- Soto M, Andrieu S, Nourhashemi F, Ousset PJ, Ballard C, Robert P, et al. (2015), Medication development for agitation and aggression in Alzheimer's disease: review and discussion of recent randomized clinical trial design. *Int Psychogeriatr* **27**: 181-97.
- Spillantini MG, Crowther RA, Jakes R, Hasegawa M, Godert M (1998), Alpha-synuclein in filamentous inclusions of Lewy bodies from Parkinson's disease and dementia with Lewy bodies. *Proc Natl Acad Sci USA* **95**: 6469-73.
- Steinberg M (2016), Isn't your staff trained to manage my mother? *Am J Psychiatry* **173**: 205-7.
- Tariot PN, Blazina L (1993), The psychopathology of dementia. In *Handbook of Dementing Illnesses*, Morris J, ed. New York: Marcel Dekker, pp. 461-475.
- Ueda K, Fukushima H, Masliah E, Xia Y, Iwai A, Yoshimoto M, et al. (1993), Molecular cloning of cDNA encoding an unrecognized component of amyloid in Alzheimer's disease. *Proc Natl Acad Sci USA* **90**: 11282-6.

Vloeberghs E, Van Dam D, Coen K, Staufenbiel M, De Beyn PP (2006), Aggressive male APP23 mice modeling behavioral alterations in dementia. *Behav Neurosci* **120**: 1380-3.

Walsh DM, Selkoe DJ (2007), A β oligomers – a decade of discovery. *J Neurochem* **101**: 1172-84.

Weldon DT, O'Hare E, Kuskowski MA, Cleary J, Mach JR Jr (1996), Alternating-lever cyclic-ratio schedule analysis of the effects of atropine sulfate. *Pharm Biochem Behav* **54**: 753-7.

Weldon DT, Rogers SD, Ghilardi JR, Finke MP, Cleary JP, O'Hare E, et al. (1998), Fibrillar beta-amyloid induces microglial phagocytosis, expression of inducible nitric oxide synthesis, and loss of a select population of neurons in the rat CNS in vivo. *J Neurosci* **18**: 2161-73.

Wilson MP, Pepper D, Currier GW, Holloman GH, Feifel D (2012), The pharmacology of agitation: consensus statement of the American Association for Emergency Psychiatry Project BETA Psychopharmacology Workshop. *West J Emerg Med* **13**: 26-34.

Wu CS, Wang SC, Gau SF, Tsai HJ, Cheng YC (2013), Association of stroke with the receptor-binding profiles of antipsychotics – a case-crossover study. *Biol Psychiatry* **73**: 414-21.

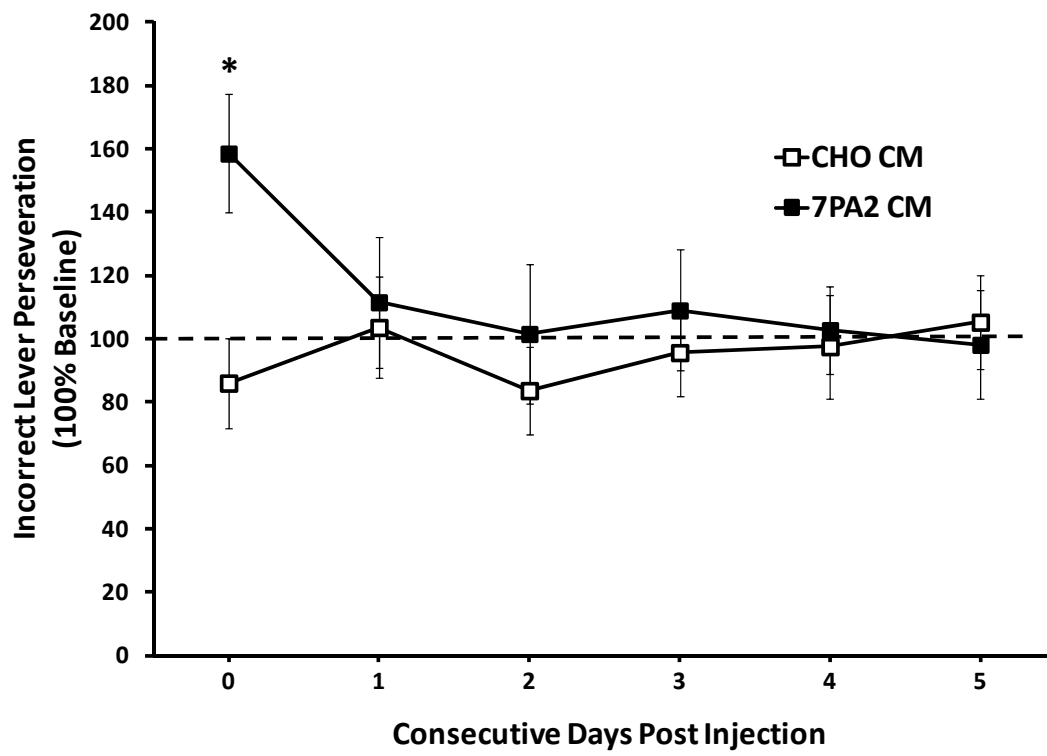


Fig. 1. Effect of ICV 7PA2 CM injection on incorrect lever perseverations, data presented as means \pm SEM (* $p < 0.001$).

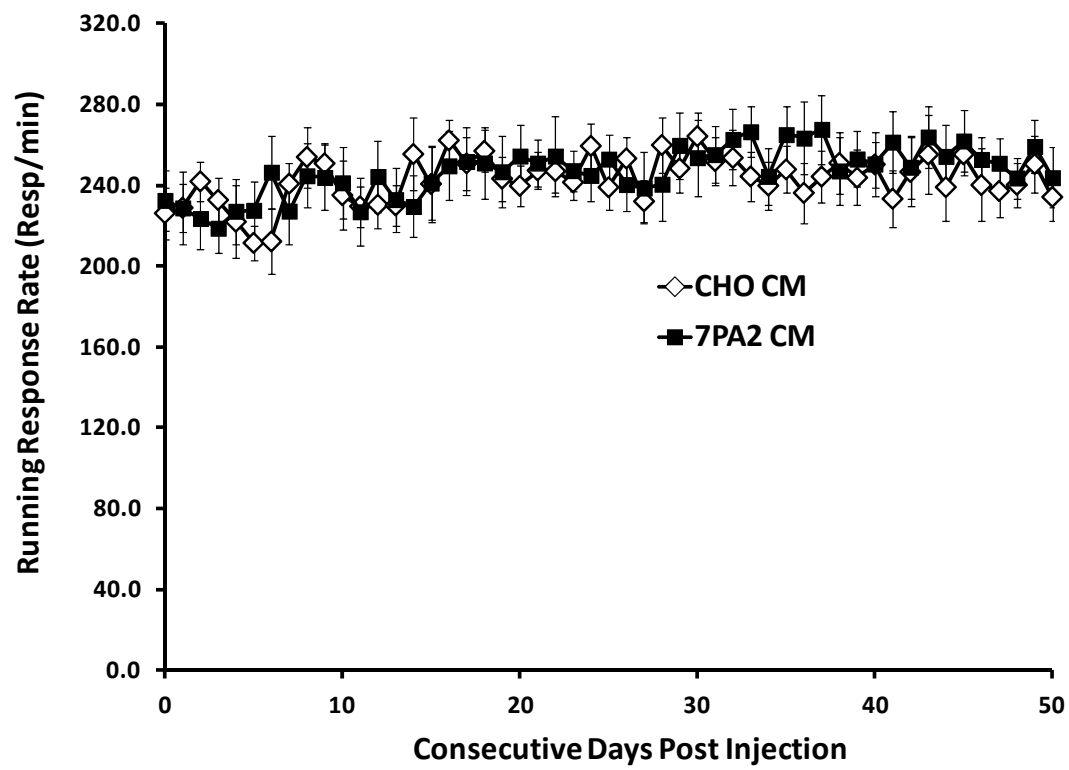


Fig. 2. Effect of ICV 7PA2 CM injection on running response rates up to 50 days post injection, data presented as means \pm SEM (repeated measures ANOVA within and between groups p 's > 0.05).

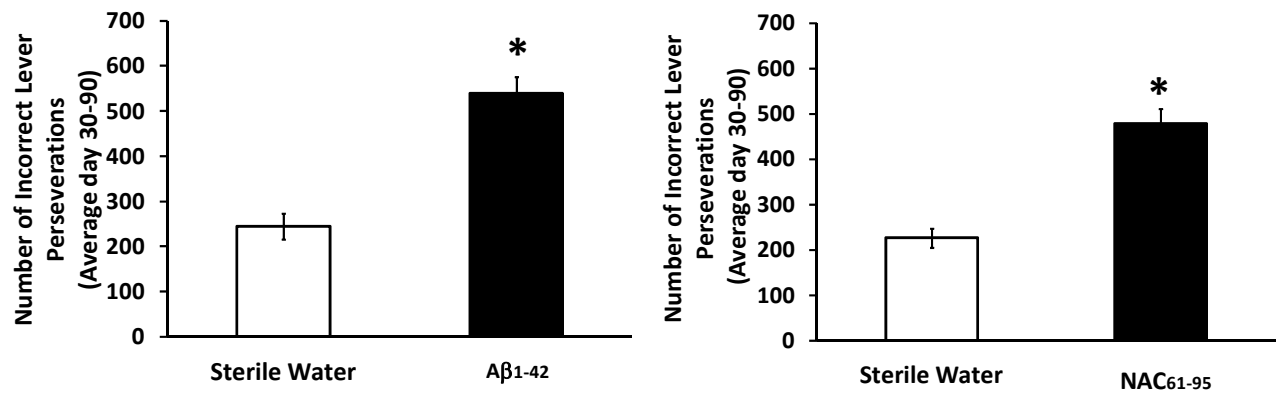


Fig. 3. Effect of bilateral IH injections of aggregated Aβ₁₋₄₂ and aggregated NAC₆₁₋₉₅ in the CA3 area of the dorsal hippocampus on incorrect lever perseverations, data presented as means ± SEM (* $p < 0.001$).

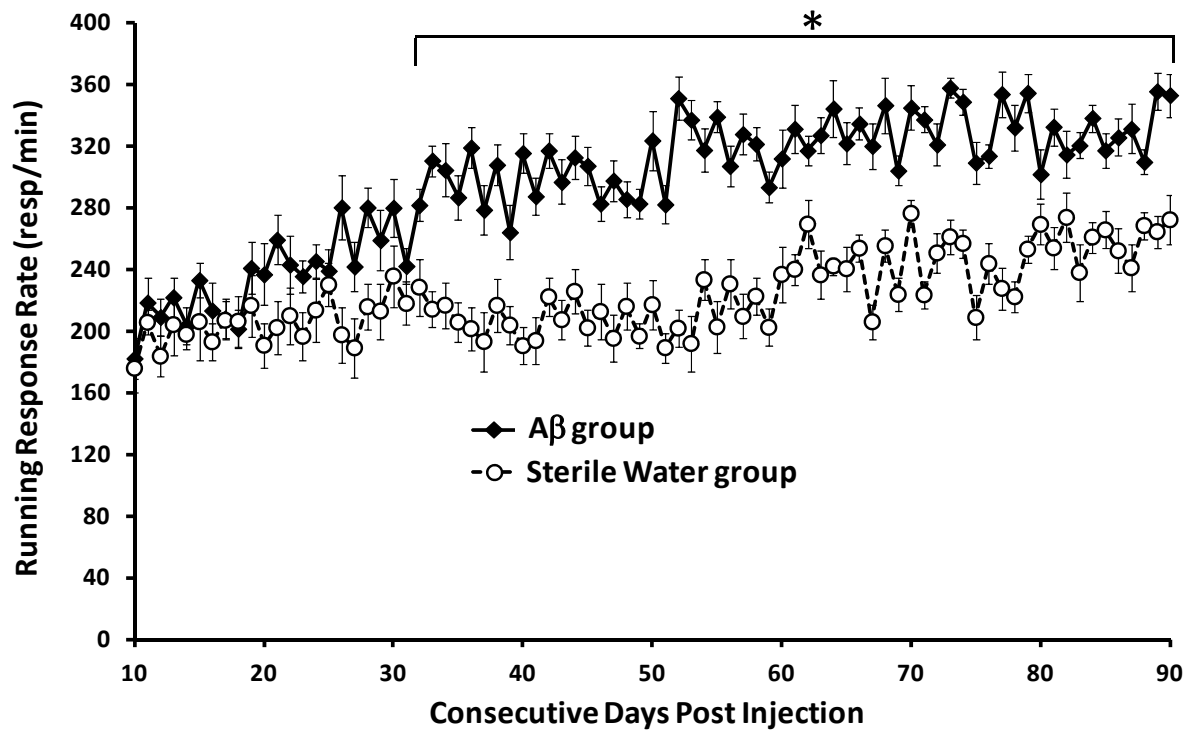


Fig. 4. Effect of bilateral IH injections of aggregated A β_{1-42} in the CA3 area of the dorsal hippocampus on running response rates, data presented as means \pm SEM (* $p < 0.001$; repeated measures ANOVA within and between groups p 's < 0.001).

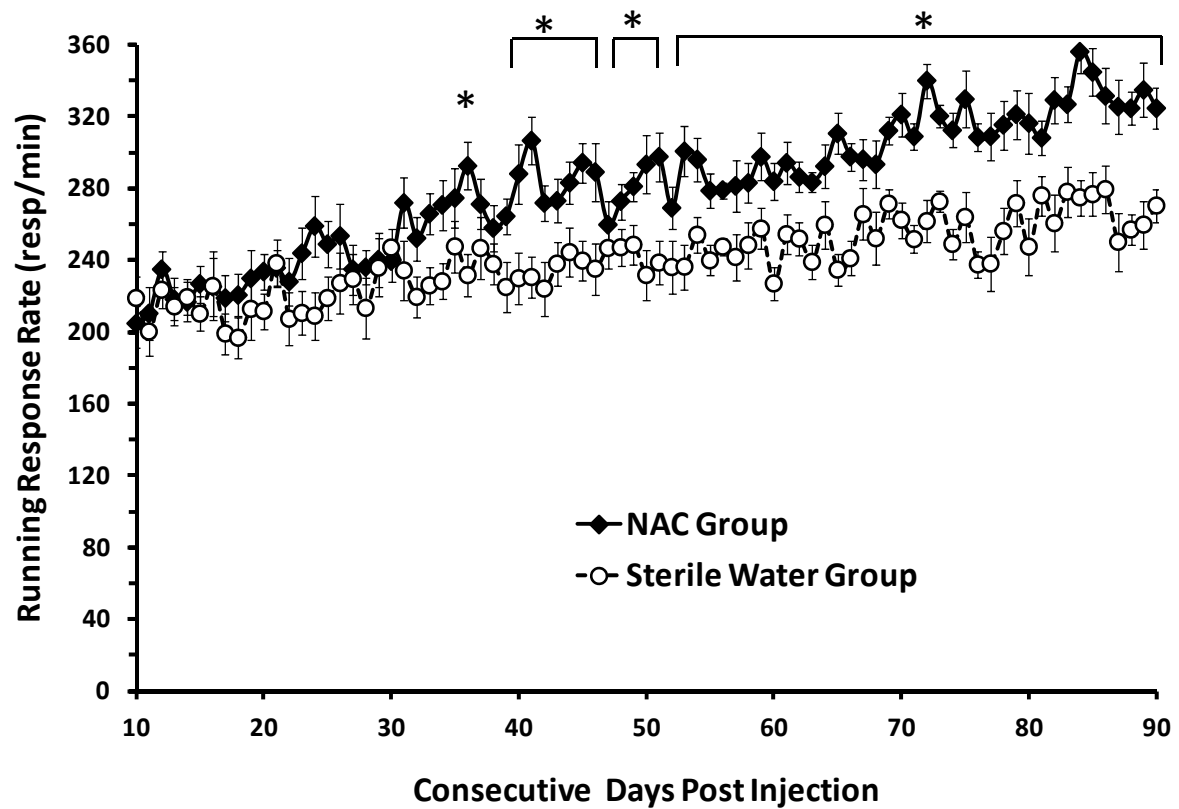


Fig. 5. Effect of bilateral IH injections of aggregated NAC₆₁₋₉₅ in the CA3 area of the dorsal hippocampus on running response rates, data presented as means \pm SEM (* $p < 0.01$; repeated measures ANOVA within and between groups $p < 0.001$ and $p < 0.05$, respectively).